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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : B60C 23/06	A1	(11) International Publication Number: WO 93/25400 (43) International Publication Date: 23 December 1993 (23.12.93)

(21) International Application Number: PCT/SE93/00526

(22) International Filing Date: 10 June 1993 (10.06.93)

(30) Priority data:
9201816-7 11 June 1992 (11.06.92) SE

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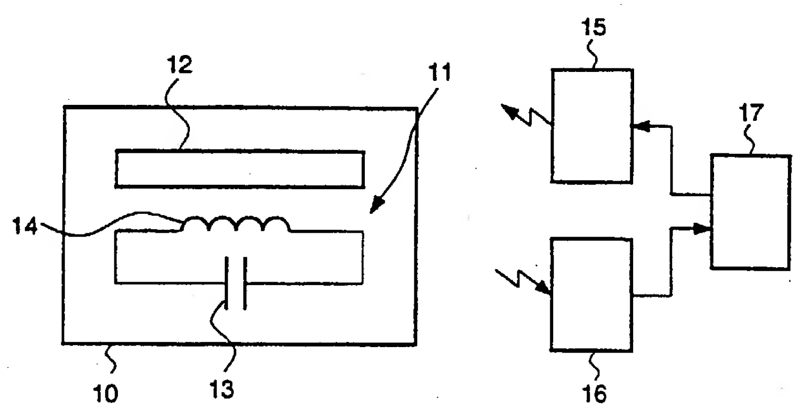
(81) Designated States: CA, JP, US, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.
In English translation (filed in Swedish).

(54) Title: SENSOR FOR MEASURING FORCE AND EXTENSION IN TYRES



(57) Abstract

A method of monitoring the force conditions in vehicle tyres during driving, whereby a signal is generated in dependence on forces occurring in the vehicle tyre and the signal is emitted to a registration unit (17) arranged at a distance from the tyre. At least one electric resonance circuit (11) is arranged embedded in the tyre and is brought to self-oscillate at a resonance frequency characteristic of the resonance circuit (11) during the giving of a signal comprising electromagnetic energy into space. The resonance frequency is brought to vary with occurring forces and strain conditions in the tyre and the variation of the resonance frequency is registered in the registration unit (17) through the reception of the electromagnetic energy.

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SENSOR FOR MEASURING FORCE AND EXTENSION IN TYRES

In vehicles having wheels with rubber tyres, the deformations/forces that occur in the tyre material give a great deal of information about the conditions that have an effect on the driving of the vehicle. It is for instance possible to register current frictional conditions between tyre and roadway and the force transmission that takes place between tyre and roadway.

Manufacturers of tyres have for many years made experiments with the purpose to achieve tyre patterns that would give a large tread surface against the roadway and high friction. At such experiments, in addition to photographing the tread surface of the tyre against a glass surface, traditional strain gauges have been used, which have been embedded in the tyre. The strain gauges have been electrically connected to the measuring equipment, which, naturally, has meant that the method of procedure has been entirely limited to experimental set-ups in laboratory environment and the like. With this type of gauge it has not been possible to transmit the measuring signal from the tyre to the measuring equipment wirelessly, which must be a pre-requisite for tests under more realistic conditions. The number of strain gauges in the tyre has also been extremely limited, in order to reduce the wiring problem.

After the development of a new type of transmitters comprising piezo-electric transmission elements formed as bands, it has become possible to improve resolution when measuring the force conditions in tyres. A system that uses this type of transmitter is shown and described in WO90/05646. In that patent specification, the tyre print is monitored by means of piezo-resistive rubber transmitters, which are embedded in the tyre. Thereby the motive force and other forces can be automatically distributed in the various tyres of the vehicle in order to optimize vehicle performance in various surrounding conditions. As this type of transmitter too generates an electric signal, the problem of transmitting the generated signal from the transmitter to the measuring and control equipment, which is required for using the measured signal, remains.

An object of the present invention is consequently to find a method

of monitoring the strain and force conditions in vehicle tyres on vehicles in normal operation, according to which is used wireless transmission of the signals from the transmitters arranged in the tyre to a receiver arranged in the vehicle. According to the method it is also achieved very high resolution of the signals that indicate the forces occurring in the vehicle tyre. Through the monitoring, registration of the so-called "slip position" is made possible, which indicates loss of gripping power. Such registration is possible even before the tyre begins to slip. This means a considerable advantage compared with so-called ABS-systems, which assume wheel locking in the control loop. Furthermore, a device has been achieved for the use of the method. Other advantages and aspects of the invention are evident from the following description and independent claims.

The invention will now be described in more detail by means of examples of embodiment with reference to the accompanying drawings, in which

FIG. 1 is an outline diagram on the device according to the invention;

FIG. 2 is a block diagram on the device according to the invention comprised in a system in a vehicle;

FIG. 3 is an outline diagram on an antenna comprised in the device; and

FIG. 4 is an outline diagram which shows the contact of a tyre against the roadway.

The device according to the invention comprises according to FIG. 1 transmitters 10, which are arranged embedded in the vehicle tyre. The number of transmitters 10 and their location and orientation in the tyre vary according to current application. With increased number of transmitters 10 follows higher resolution in the signal emitted from the transmitters in the tyre.

The transmitter 10 is formed as an electric resonance circuit 11. According

to the invention the electric resonance circuit 11 comprises a resonance frequency determining means 12, which in a preferred embodiment consists of a strip of a magnetic material. Also included in the resonance circuit 11, there is an inductive element and, in parallel with it, a capacitor 13. In a preferred embodiment, the inductive element consists of a coil 14, which is magnetically connected to the magnetic element 12. The characteristics of the capacitor 13 and the coil 14 is kept comparatively constant according to the invention, and the resonance frequency of the resonance circuit is consequently decided by the magnetic characteristics of the magnetic element 12. In an especially preferred embodiment the magnetic element consists of a strip of an amorfous material, whose magnetic characteristics change very much when being mechanically acted upon, for instance if the strip is exposed to draught or compressive forces in the longitudinal direction of the material. The function of the magnetic element is described in more detail herebelow.

For excitation of the electric resonance circuit 11, an electric excitation means 15 is arranged. The excitation means 15 comprises a radio transmitter, not shown, which is formed to give an electromagnetic wave, which brings the electric resonance circuit 11 to self-oscillation. When the electric resonance circuit 11 self-oscillates, electromagnetic energy is emitted into space, and this energy is received by a receiver 16, which can be a radio receiver of conventional type. The receiver 16 and excitation means 15 are operatively connected to a registration unit 17.

The force-sensing part of the transmitter 10 according to the invention is constituted by the magnetic element 12. In a preferred embodiment this is constituted by a core or a band of an amorfous material. The longitudinal direction of the band decides the strain-sensitive axle of the transmitter. This is consequently directed in the direction along which the mechanical strain condition is desired to be registered with the current transmitter. The magnetic element 12 is magnetically connected to a coil 14, which can be wound in a conventional way or formed as a printed conductive pattern. In an alternative embodiment the inductive element and the magnetic element are joined in a so-called "cloth

inductor" in which the elements are joined in a cloth-like structure. This embodiment gives a very high magnetic connecting factor between the magnetic element and the inductive element. This embodiment is also very suitable if it is desired that the transmitter be formed as a layer in the form of a rubber film or the like. Such a film is put in as a layer in the tyre, in the tyre manufacturing process. An advantage with this embodiment is that a correct transmission geometry in the tyre is ensured, with no directional processes afterwards.

When the magnetic element is exposed to mechanical actions, its magnetic characteristics change. Through the connection to the coil 14, the characteristics of the coil and the resonance frequency of the resonance circuit change as well. Thereby it is also possible, by registering a change in the resonance frequency about a normal or centre frequency, to register strain or deformation in the tyre material surrounding the transmitter.

A suitable practical location of the registration unit 17, the excitation means 15 and receiver 16 is shown in FIG. 2. In a preferred embodiment the registration unit 17 is arranged centrally in the vehicle in connection with other central electronics. At each wheel an excitation means 15 and a receiver 16 are arranged. The number of excitation means 15 and receivers 16 can vary in dependence on the number of transmitters 10 in each tyre. When there is a great number of transmitters 10, the embodiment shown in FIG. 2 is suitable, to get a simpler embodiment of the comprised components. In this embodiment it is important that the receiver 16, or at least an antenna connected thereto, is arranged so that only transmitters in the tyre in question are registered. Such a local registration can be achieved, for example through adjustment of the range or signal-sensing sector of the antenna. It is also possible, especially through the location on the vehicle and/or adjustment of the type of antenna, to achieve the desired local registration. In a practical embodiment the receiving antenna is located in each wheel housing on a car, whereby the desired tyre-selecting effect is obtained. A central location of the receiver 16 or its antenna, in the middle of the vehicle, is also possible. Thereby, it is possible with one single antenna and a registration unit 17 to monitor all the wheels of the vehicle.

The resonance frequency is chosen to be unique for each transmitter 10, at least if only one transmission and receiving antenna is used, so that it will be possible in the registration unit to distinguish the signals from the different transmitters 10. If every wheel is provided with a separate transmission and receiving antenna, only the transmitters in the respective tyres need to be distinguishable.

FIG. 3 shows a combined transmission and receiving antenna. A transmission antenna 18, which is operatively connected to the excitation means 15, in the form of a single loop of rectangular form, comprises a receiving antenna 19, which is formed as an eight, and works as a balanced frame antenna. The receiving antenna 19 is operatively connected to the receiver 16. The embodiment of the antenna arrangement shown in FIG. 3 is advantageous, because transmission and receiving at the same frequency is facilitated. Other, more or less conventionally formed, antenna systems are also possible to apply within the scope of the invention. As the resonance circuit 11 also emits a certain energy in frequency intervals other than its own, for example overtones of the resonance frequency, it is also suitable in certain applications to excite the resonance circuits at a frequency and detect the resonances at another frequency.

The condition in tyres that especially can be registered and used for the control and monitoring of the whole vehicle is shown in FIG. 4. A gas-filled tyre which under load is pressed against a bed or a roadway is compressed and gets a flat tread surface against the bed. In the area around the tread surface the tyre radius is smaller than in other parts of the tyre. In the border area between parts with diminished radius and parts with unchanged radius, forces appear in the tyre as a consequence of the compression of the tyre in the periphery in the arc sector interval that is in contact with the bed. The compression occurs when the tyre pattern is rolled into contact with the roadway, and the tyre expands again when the tyre pattern rolls out of contact with the bed. The deformation picture in the tyre rubber in the tread surface is dependent on the friction against the roadway. If the friction is below a certain level, the deformation picture changes due to the fact that the strain force locally, in parts of the tread surface then

becomes as large as the frictional drag, and consequently these parts of the tread surface slips on the bed. Under these circumstances, the gripping power and friction can be measured. The larger the moment of the wheel, the greater the likelyhood that this should occur, but it always occurs before the wheel loses the grip entirely and starts slipping uncontrollably.

At low friction, this occurs already in normal driving of the vehicle with a moderate moment on the wheels. This implies that the gripping power/friction can be measured continuously, and also when the wheel runs completely free, through measuring and analysis of the deformation in the tyre during rolling against the roadway.

For a reliable measurment of the deformations in the tyre, the number of transmitters 10 and the location and orientation of the transmitters in the tyre are adjusted. The number of transmitters per tyre is chosen in dependence on the number of dimensions in which the deformation or strain condition is desired to be resolved, the number of registration points per tyre rotation desired and the desired resolution in the deformation or strain condition in the axial direction of the tyre, that is, in the direction perpendicular to the rolling direction of the tyre. For measuring the friction between the tyre and the bed, registration of the tangential stress in the rolling direction is of dominating importance. If also monitoring of the force transmission between the vehicle and the roadway is to be achieved, measuring shall also take place in the contact plane between the tyre and the roadway, either one-dimensionally in the rolling direction or two-dimensionally in the rolling direction and in the lateral direction.

The number of transmitters per tyre varies in different applications from one single per tyre, in which arrangement frictional measuring is obtained only once per wheel rotation, to about 60 transmitters per tyre, in which arrangement almost continuous measuring of friction is obtained and, in addition, measuring of three-dimensional strain conditions in the tyre.

The location of the transmitters in the tyre structure is so chosen, that good or, rather, optimal sensing of the mechanical strain flow from the road to the vehicle is achieved. It is also essential that the local deformation picture of the tyre pattern that mirrors the current gripping power or friction can be sensed. Suitably, the depth of the location in the tyre of the transmitters 10 is chosen so that the transmitters 10 remain protectedly embedded during the entire lifetime of the tyre. Another factor in choosing the depth of location for the transmitters is that the degree of stetch for the transmitters decreases the closer to the cord the transmitter is located. The extensibility of the transmitter 10 and its signal level relative to the stretch can be decisive for the location of the transmitter in the tyre.

In certain embodiments of the invention the transmitter 10 is located at various depths in the tyre, whereby a radial stretch gradient gauging is obtained. Through this measuring, information on the elastic characteristics of the rubber and also of the current depth of the tread surface is also obtained. Hereby, an indication on the wearing condition of the tyre is possible on a display or the like in the instrument board of the vehicle. By arranging several transmitters 10 in the axial direction of the tyre, information is obtained on varying friction between the tyre and the bed in the axial direction of the tyre. The total grip in the axial direction of the tyre is thereby determined as the sum, or integral, of the signals from the various transmitters.

Through the number of transmitters 10 in the peripheral direction of the tyre, the desired degree of continuity in the measuring signal information from the transmitters 10 is chosen. As the tyre normally rolls, each transmitter runs through the various strain conditions that exist in the road-contact length, and also other parts of the periphery of the tyre, during a wheel rotation. Hereby, only one transmitter per tyre, and for every desired strain direction is required, to obtain basic information on the force conditions in the vehicle tyre. When, contrarily, the tyre is locked and does not roll but slips, more transmitters are required along the contact length, if a safe signal from the contact surface is to be obtained. In a suitable embodiment according

to the invention the number of transmitters 10 is so chosen, that one transmitter 10 leaves the contact zone when the next transmitter comes into the contact zone. In a tyre of normal size this means a peripheral distance between successive transmitters of about 10 cm.

With a more tight location of the transmitters 10, a very complex monitoring of the current movement of the tyre relative to the bed is made possible. If several transmitters are located in that portion of the tyre that is in contact with the bed, registration is made possible of separate zones of the tyre, which are, respectively, in gripping contact with the bed and has started slipping. Through the determination of the conditions between the surfaces of the zones, the beginning of slipping in the tyre and the so-called "slip position" can be determined very accurately. Edge zones between the resting friction and the movement friction are also possible to decide. The result of the monitoring is used for example to pre-warn of wheel locking on braking, skidding on curve-taking, before such conditions occur. It will also become possible in a smooth way to distribute the power transmission to different driving-wheels, so that the best driving conditions possible are obtained.

Also an existing, "conventional", tyre can be equipped with transmitters according to the invention. Preferably a procedure similar to providing studs is used. In cavities which have been created through boring or the like, rubber elements comprising one or more transmitters are located. The rubber element is fixed and integrated with the rubber structure of the tyre through a vulcanizing or rubber gluing process. Through a suitable choice of location and orientation for the rubber elements the desired information on the force conditions in the vehicle tyre is obtained.

Through the integrated embodiment of transmitters in the tyre structure, sensing of tyre ruptures are also made possible. A cracking pattern tread immediately brings about considerable changes in the deformation picture of the tyre rubber during the rolling of the wheel, which the transmitters 10 register through a much changed resonance frequency. On sensing the changed resonance frequency in the registration unit 17, an alarm con-

cerning a beginning tyre rupture is initiated. If the damage brings about that pieces of rubber are released from the tyre and thrown away, this means that possibly also the transmitters 10 are thrown away or distroyed. This means also loss of the signals from these transmitters and is a further indication on tyre damage and to a certain degree also designation of the kind of damage.

Among the factors that have an effect on the signals from the transmitters 10, the following may be mentioned: changes in the elastic characteristics of the rubber; the current temperature of the rubber; the rotational speed of the wheel; and the air pressure in the tyre. Changes in the elastic and viscous characteristics of the rubber are compensated for through electronic adjustment in the registration unit 17. This compensation is comparatively easy to achieve, because the changes occur slowly and can be registered, for example at the first rotation of the wheel after a stationary state. A more careful determination of the elastic characteristics of the rubber or tyre can be achieved through suitable location and orientation of several transmitters in the tyre structure.

Temperature dependent changes in the elastic characteristics of the tyre can be dealt with in a corresponding way. It is also possible, through the integration of special temperature sensors in the tyre, to measure the temperature of the tyre rubber, and this information on the temperature can be used by the registration unit 17 for the compensation of temperature changes that affect the transmission signals.

The rotational speed of the wheel affects the strain picture of the tyre, partly through increased centrifugal load on the tyre and partly through a certain change of the geometry of the road-contact surface. In addition, the contact impact acceleration becomes higher when the contact zone is rolled through. By registering the speed at which the transmitters pass through the antenna sensing zone, information is obtained on the current rotational speed of the tyre. Thereby, compensation can be made with respect to the effect that the wheel speed has on the strain picture in the tyre and thereby also on the subsequent analysis on friction and roadway interaction forces. At higher wheel rotational speeds there

will be a risk for aquaplaning. This occurrence will be mirrored in the tyre deformation picture in the surface that is in contact with the roadway, and the registration unit 17 can be arranged to give an early warning of this.

Through the registration of the strain conditions in the parts of the tyre that are not currently in contact with the roadway, measuring of current gas pressure in the tyre is made possible. Any change in the tyre pressure is reflected directly in the signal picture from the transmitters in the tyre, and by measuring the gas pressure, compensation in the registration unit 17 for the changes is made possible. In addition, the information on the pressure in the tyre is directly useable for other purposes, for example indication of the pressure on the instrument board.

The possibilities of using the signals dependent on the force conditions in the vehicle tyres are almost unlimited. In a simple embodiment according to the invention the signals for audio och visual skidding warning are used. A far more complicated use leads to almost total control of driving and breaking wheel moments and wheel angles in order to give the vehicle the movement path which the vehicle operator, through the conventional controlling means of the car, indicates the vehicle to follow.

Claims

1. A method of monitoring the force conditions in vehicle tyres during driving, whereby a signal is generated in dependence on forces occurring in the vehicle tyre, and the signal is emitted to a registration unit (17) arranged at a distance from the tyre, c h a r a c t e r i z e d in
   that at least one electric resonance circuit (11) is arranged embedded in the tyre,
   that the electric resonance circuit (11) is brought to self-oscillate at a resonance frequency characteristic of the resonance circuit, on emitting a signal comprising electromagnetic energy into space,
   that the resonance frequency is brought to vary with occurring forces and strain conditions in the vehicle tyre, and
   that the variation of the resonance frequency is registered in the registration unit (17) through the reception of the electromagnetic energy.

2. A method according to claim 1, c h a r a c t e r i z e d in
   that signals from several resonance circuits (11) embedded in a portion of the tyre that is in contact with a bed are emitted and received by the registration unit (17), som that the appearance of zones in the tyre that slips against the bed is registered, before the whole portion, in contact, slips.

3. A device for monitoring the force conditions in vehicle tyres on a vehicle during driving, comprising means (10) for producing and giving a signal in dependence on forces occurring in the vehicle tyre and a registration unit (17) arranged at a distance from the tyre, for receiving the given signal, c h a r a c t e r i z e d in
   that at least one electric resonance circuit (11) with characteristic resonance frequency is arranged embedded in the tyre for transmitting electromagnetic energy into space,

that the electric resonance circuit (11) comprises a resonance frequency determining means (12), whose characteristics are dependent on the forces occurring in the vehicle tyre,

that an excitation means (15) is arranged for excitation of the electric resonance circuit (11) to self-oscillate,

that the registration unit (17) is operatively connected to at least one receiver (16) for receiving the electromagnetic energy indicating the resonance frequency of the resonance circuit (11).

4. A device according to claim 3, characterized in that the resonance frequency determining means (12) is formed as a band of an amorfous material.

5. A device according to claim 3, characterized in that the electric resonance circuit (11) comprises a coil (14), which is arranged magnetically connected to the resonance frequency determining means (12).

6. A device according to any one of claims 3-5, characterized in that the resonance circuit (11) of every transmitter (10) in a vehicle tyre is arranged so as to self-oscillate at a unique resonance frequency in an unloaded condition.

7. A device according to any one of claims 3-6, characterized in

that at each vehicle tyre a separate excitation means (15) and a separate receiver (16) are arranged,

that at each vehicle tyre a transmission antenna (18) operatively connected to the excitation means (15) is arranged,

that at each vehicle tyre a receiving antenna (19) operatively connected to a receiver (16) is arranged.

8. A device according to any one of claims 3-6, characterized in

that the vehicle is provided with an excitation means (15) which is mutual for all the vehicle tyres, and a receiver (16) which is mutual for all the vehicle tyres, and

that at each vehicle tyre a separate transmission antenna (18) and a separate receiving antenna (19) are arranged.

9. A device according to any one of claims 3-6, c h a r a c t e r i z e d in

that the vehicle is provided with an excitation means (15) which is mutual for all the vehicle tyres, and a receiver (16) which is mutual for all the vehicle tyres, and

that centrally in the vehicle, a transmission antenna (18) and a receiving antenna (19) are arranged.

10. A device according to any one of claims 3-8, c h a r a c t e r i z e d in

that the resonance frequency determining means (12) are arranged in the vehicle tyre for sensing forces in the peripheral direction of the vehicle tyre.

11. A device according to any one of claims 3-8, c h a r a c t e r i z e d in

that the resonance frequency determining means (12) are arranged in the vehicle tyre for sensing forces in the axial direction of the vehicle tyre.

Fig 1

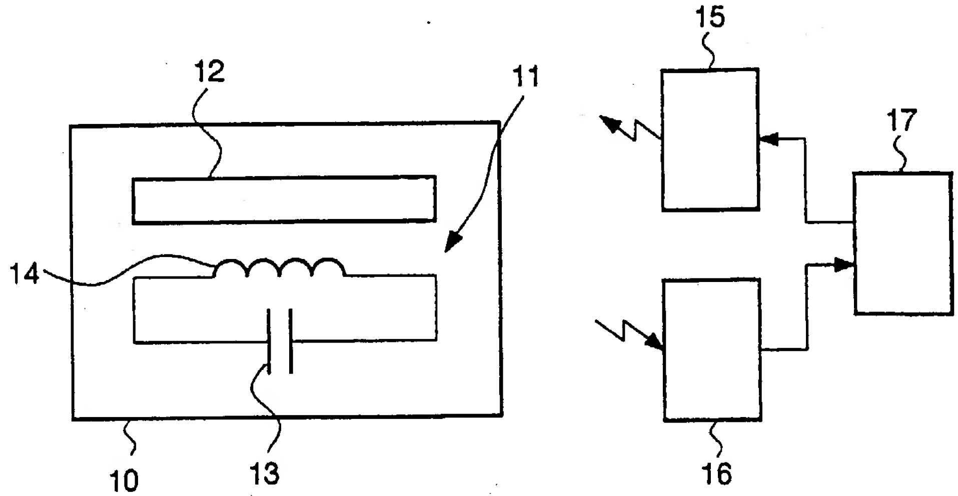


Fig 2

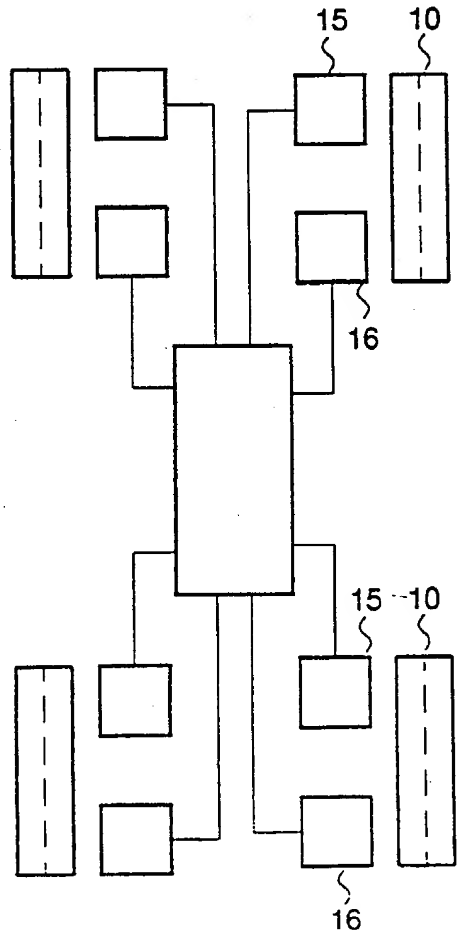


Fig 3

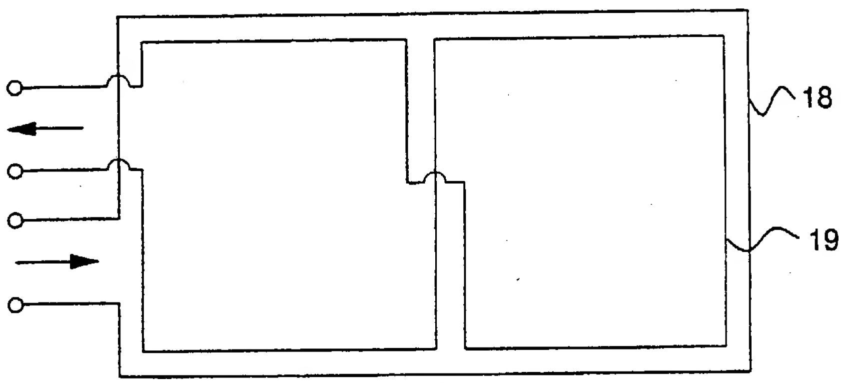
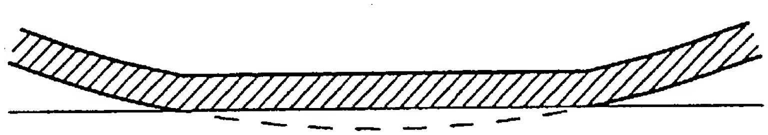


Fig 4



INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 93/00526

A. CLASSIFICATION OF SUBJECT MATTER

IPC5: B60C 23/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC5: B60C, G01M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US, A, 4300119 (WIERNICKI), 10 November 1981 (10.11.81) --	1,3
X	US, A, 4376931 (KOMATU ET AL), 15 March 1983 (15.03.83) --	1,3
X	US, A, 4588978 (ALLEN), 13 May 1986 (13.05.86) --	1,3
X	US, A, 5006844 (OHTA ET AL.), 9 April 1991 (09.04.91) -- --------	1,3

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
16 Sept 1993	20 -09- 1993
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Göran Carlström Telephone No. +46 8 782 25 00

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT
Information on patent family members

26/08/93

International application No.
PCT/SE 93/00526

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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